DOCUMENT RESUME

ED 440 887 SE 063 666

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TITLE The Desired Image of a Science Writer.
PUB DATE 2000-04-00
NOTE 38p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (New Orleans, LA, April 28-May 1, 2000). Presented in a different form at the Annual Meeting of the European Science Education Research Association (Kiel, Germany, August 31-September 5, 1999).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Higher Education; Role Models; *Role Perception; Science Education; *Scientists; Writing Attitudes; Writing (Composition); Writing Skills

ABSTRACT

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The Desired Image of a Science Writer

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The Desired Image of a Science Writer

Abstract

This study attempted to establish a desired image of an expert science writer based on a synthesis of writing theory, models, and research literature on academic writing in science and other disciplines and to contrast this desired image with a actual prototypical image of scientists as writer of science. The synthesis was used to develop a questionnaire to assess scientists' writing habits, beliefs, strategies, and perceptions about print-based language. The questionnaire was administered to 17 scientists from science and applied science departments of a large Midwestern land grant university. Each respondent was interviewed following the completion of the questionnaire with a custom-designed semi-structured protocol to elaborate, probe, and extend their written responses. These data were analyzed in a step-wise fashion using the questionnaire responses to establish tentative assertions about the three major foci (type of writing done, criteria of good science writing, writing strategies used) and the interview responses to verify these assertions. Two illustrative cases (a very experienced, male physical scientist and a less experienced, female applied biological scientist) were used to highlight diversity in the sample. Generally, these 17 scientists are driven by the academy's priority of publishing their research results in refereed, peer-reviewed journals. They write their research reports in isolation or as a member of a large research team, target their writing to a few journals that they also read regularly, use writing in the teaching and scholarship to inform and persuade science students and other scientists, but do little border crossing into other communities. The actual prototypical science writer found in this study did not match the desired image based on a synthesis of the writing literature in that these scientists perceived writing as knowledge telling not knowledge building and they used a narrow array of genre, strategies, target audiences, and expectations for their writing.

The Desired Image of a Science Writer

Introduction

The current science education reforms in Australia, Canada, New Zealand, the United Kingdom, and the United States promote science literacy for all students that focuses on citizens' responsibilities and active participation in the global community. Collectively, these reforms describe science literacy as people's abilities and habits-of-mind that allow them to construct understanding of the big ideas in science, to apply these science ideas to realistic problems and issues involving science, technology, society and the environment, and to inform and persuade other people to take informed action based on these science ideas. Furthermore, research at elementary schools, secondary schools, colleges, and universities highlights the value of writing in science to promote learning and to promote technical science writing (Chinn & Hilgers, 2000; Prain & Hand, 1999; Yore, 2000). Clearly this contemporary definition of science literacy and the subsumed teaching and learning approaches establishes oral and written language as an end and a means to science literacy. This notion of science literacy also implies that students should form a sense of themselves as writers in and of science, committed to the particular epistemological beliefs and procedures that such a self-concept entails.

In promoting science literacy some post-secondary institutions have required the completion of writing-intensive courses as part of their graduation requirements. Likewise, academic departments have picked up on science writing as a goal for science and engineering programs and as an instructional strategy. Many science educators have realized that writing about science provides an effective context for reflection and consolidation of science understandings initiated during laboratory investigations, lectures, tutorials, reading assignments, and class discussions. They also have realized that their graduates will need to communicate with numerous audiences and to utilize various genres as professional scientists and engineers. The success of these attempts appear to involve the authenticity and the pedagogical foundation of the writing tasks.

The renewed interest on written communications in science and technology has placed demands on literacy and science researchers to document the attributes of an effective science writer and learner and to explore the effectiveness of writing-to-learn science. This study attempts to document the characteristics, values, beliefs, attitudes, knowledge, and strategies of experienced science and technology writers as they address authentic communication demands by use of a questionnaire and follow-up interview as a first step in describing the desired image of a science writer. The desired image may provide a vision for technical writing programs in universities and colleges and a framework of authentic writing types, criteria for good science writing and science writing strategies for writing-to-learn science in elementary and secondary schools. Furthermore, this prototypical image will help identify differences between novice and expert science writers to guide assessment of science writing.

Background

Writing to learn or writing across the curriculum has been a grassroots movement in the English-speaking countries in which its popularity has ebbed and flowed. There has been a great deal of research on writing; however, there has been less consideration of scientific and technical writing, the transition of apprentice to journeymen science writer, and the application of writing as a learning tool within science classrooms (Chaopricha, 1997). During the last decade researchers have begun to look more critically at the limited types of writing that occur in science classrooms and how these traditional writing types can be supplemented with non-traditional forms. As well as the limited work on the use of a wider variety of authentic forms of writing, little research has been done that examines the nature of writing, the nature of science, and the nature of science learning (Rowell, 1997). The emphasis on the nature of science learning is important, given the difference between school science and science in general (Driver, Leach, Millar & Scott, 1996). Clearly such research will need to consider how science ideas are represented in the scientific, school, and broader communities and how these differences can be used to improve science literacy instruction. Given the expanded demand for science literacy in terms of time in the curriculum, more attention is being given to writing in science classrooms and how an increased variety of authentic science writing tasks might increase both science understanding and technical writing performance. While

there has been much debate over the writing processes that should be adopted in science classrooms, recognition has been given to the value of using writing to help students construct understanding of science (Holliday, Yore & Alvermann, 1994; Kelly & Chen, 1999; Keys, 1999; Prain & Hand, 1996). This recognition extends beyond the traditional forms of science writing to include interaction with various communities (border crossings) involved in the public debate about science, technology, society, and the environment issues that students as life-long learners will need to engage. Currently there exists limited understanding of the writing processes that expert scientists use to inform different audiences of their work, how the nature of science influences the characteristics and content of science writing, and how these processes can be reflected in science classrooms (Yore, Hand & Prain, 1999). This paper begins this process by describing a desired image of a science writer as a vision of a scientist reporting science, a framework of desirable dispositions and strategies in representing science understanding, and a guide for writing-to-learn science programs.

The Process of Writing

The work of Hayes and Flower (1986) and Bereiter and Scardamalia (1987) provides an overview of writing and defines writing as an act of communication. Galbraith and Rijlaarsdam (1999) suggested there are three processes that writers' use: intentional cognition, managing the process, and the social nature of writing. Intentional cognition refers to the communicative goal of the writer. Bereiter and Scardamalia (1987) believed that novices' communicative goal is knowledge telling, whereas an expert's goal is knowledge transformation. As opposed to knowledge telling, knowledge transformation (knowledge building) is an act of learning where there is a dynamic between the content being addressed and the rhetorical requirements of the writing task. This dynamic leads to a constant evaluation and transformation of an individual's knowledge. Keys (1999) suggested that expert science writers actively attend to both the content and rhetorical requirements in the knowledge transformation process of writing, while novices struggle with the rhetorical aspects of the writing. She stated

> In the content space, the problems and beliefs are considered, while in the discourse space, the problems of how to express the content are considered. The output from each

> space serves as input for the other, so that questions concerning language and syntax choice reshape the meaning of the content, while efforts to express the content direct the ongoing composition. (p. 120)

Thompson (1993) stressed that, since science is inquiry and argumentation, the expert scientist writes to persuade others and therefore must focus on the rhetorical components of the process as a crucial element of the writing process. Bereiter and Scardamalia (1987) suggested that this recursive attention on matching the content to the rhetorical goals of writing helps develop an individual's understanding.

Klein (1999) described four models of writing to enhance understanding: spontaneous utterance, forward search, genre-related and backward search. The first model assumes writing shapes thought at the point of formation, in that the act of converting mental models and ideas into printed expression makes tacit understandings more explicit. The forward search model asserts that writers transform their ideas by ongoing analyses of their texts in terms of expanding inferences, reviewing idea development, noting contradictions, and making appropriate revisions. The genre-related model maintains that the use of different function-form frameworks (genre) and knowledge of textual microstructures and macrostructures enables the writer to identify relationships among ideas and clarify understanding of the embedded ideas. The backward search model argues that setting and addressing rhetoric and conceptual goals allows writers to learn through writing as they monitor internal coherence, strength of argument, relationships among claims, evidence and warrants, and attainment of their goals.

The second process, managing the writing process, is centred around three metacognitive actions used when writing: planning, translating, and revising. Zimmerman and Risemberg (1997, p. 74) described these actions as

> Planning involves three cognitive subcomponents: generating information that might be included in the composition, setting goals for the composition, and organizing the information that is retrieved from memory. Translating is the process of converting ideas into textual output, and reviewing involves two subcomponents: evaluating and revising text as it is translated.

Galbraith (1992, p. 51) noted that managing these processes requires the writer to engage both the "conceptual combinations [of the subject] embedded in semantic memory and the linguistic resources for expressing these conceptual relationships". However, he later pointed out that novices tend to try and deal with planning, translating and revising all at once, whereas experts tend to focus on each function separately.

The third process, the social nature of writing, moves past the individual writer to focus on the interaction between the writer and the reader. As writers move between different communities, there is a need to be aware of the discourse of these communities and to match the goals of the writing to these communities (Flower, 1994; Galbraith & Rijlaarsdam, 1999). Ferrari, Bouffard, and Rainville (1998, p. 486) suggested that, along with a better understanding of the rhetorical and linguistic demands of writing, expert writers appear to "have a clear appreciation of how one's goal in writing will be received by one's audience". Fahnestock and Secor (1986) suggested that scientists need to persuade readers of their arguments and thus must pay careful attention to the demands of the audience if they are to be successful. Best (1995, p. 9) stated that "expert writers seemed to synthesize information, re-arrange their material and locate what may appear weak, to prepare prose which accommodates the reader". Galbraith and Rijlaarsdam (1999) suggested that emphasis on the planning phase of the writing process (i.e., part of the managing process above) is crucial because the writer needs to maximize cognitive space in order to adjust to the demands of the intended audience. Writers not only need to plan effectively to focus on the audience but they must also "devote personal time and effort necessary to revise text drafts until they communicate effectively" (Zimmerman & Risemberg, 1997, p. 76).

A synthesis of literature suggests that expert science writer have and apply domain and topic knowledge, metacognitive awareness and executive control of science discourse, and writing strategies to solve written communication problems (Yore, 2000). These experts deliberately build representation of the general problem space associated with the communication problems being addressed using their mental models of content and written discourse before trying to fine tune the schema to a specific problem (Chaopricha, 1997). This allows the science writer to test the appropriated schema against the

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demands of the specific task. It is this extensive grappling with the demands of an authentic communication problem that allows the writer to master the cognitive, linguistic, and rhetorical abilities and conventions and expectations of good science writing.

The science research report genre (introduction, methods, results and discussions) is the predominant schema in science and it drives science writing toward the discipline's norms, values and ideology and a rather narrow set of writing strategies, knowledge representations and expectations of writing. Chaopricha (1997) stated:

> Any claim to the priority of discovery requires suitable, trustworthy, and persuasive methods for communicating the work that constitutes the claim to priority. Verbal or informal communication is not sufficient. The production of a written scientific research paper is needed as a record in case of dispute. For this reason, the publication of scientific research in recognized journals is necessary to ensure the dissemination of the discovery to the potential audience. However, the thrust of the research findings provided involves a quest for agreement from the members of the community. Personal findings are referred to the community of scientists in the form of scientific research papers intended to persuade other scientists to validate its scientific status. (p. 12)

Science writers frequently define their audience as other reasonably well-informed scientists with similar ontological and epistemological views of science, understandings about scientific discourse and disciplinary specialty. Bazerman (1988) believed that good writers need to cross boundaries of conventions, discourse and communities rather than adopt a narrow template for their writing.

Expert science writers use several strategies to establish authority, common understanding and creditability. Scientists use other accepted text in their written text (intertexuality) to justify their procedures and claims. "Citation of references is the most obvious manifestation of this scholarly bricklaying" used to demonstrate how the current methods and knowledge claims build on established research procedures and authorized knowledge (Chaopricha, 1997). This introductory background not only establishes a platform for authority and creditability, but also attempts to establish common

understandings for the author and reader. Nystrand(1986) states that "skilled writer elaborate potential troublesome parts of text [such as terms and concepts which are critical to reader comprehension] and the general requirements for semantic coherence" (p. 118). Any point in the communication which endangers or potentially disrupts the established frame of reference and comprehension is a choice point that the writer must provide local elaboration (definitions, examples, illustrations, diagrams, analogies, metaphors, etc.) to buttress the text and reinstate reciprocity of the writer's purposes and the reader's needs.

Novel findings are highly valued within the scientific community, but they run the chance of being discounted if they are not anchored to established procedures, accepted analyses and data interpretation, and canonical theory. Analysis of the most frequent scientific citations clearly illustrates the impact of science ideas, the persuasiveness of the associated written research report and the status of the authors. The case of A.E. Sutherland, 1971 Nobel Prize winning biochemist, illustrates the affect of a ineffectively titled or crafted research paper that does not attract the proper attention of the appropriated scientific community (Sinding, 1996). Sutherland's 1957 paper "Cyclic AMP and Hormone Action" that was the basis for his Nobel Prize did not attract much attention and was not frequently cited in the early years. Its full impact was not realized until a 1964 conference presentation highlighted the earlier findings to endocrinologists by using the analogy of AMP as the second messenger for hormone action.

Contemporary science frequently involves team of researchers with a common interest but different expertise and perspectives working in a sociocultural context (Bakhtin, 1986; Nystrand, 1986). The research activities (design, data collection, data analysis, interpretation of results, etc.) and the publication of the findings provide opportunities for convergence of these diverse talents and insights, intense negotiations, and construction of shared understandings. Furthermore, the editing of drafts and addressing reviewers' comments provide focused interactions among team members in which text and content will be modified to maximize the clarity and accuracy of the science report. These debates and negotiations are integral parts of the inquiry, composition, and writing in science. Clearly, expert science writing involves much more than displaying resolved knowledge to other like-minded scientists and the physical act of putting these known ideas into print.

Nature of Science

Science utilizes unique patterns of argumentation that attempt to establish clear connections among claims, warrants, and evidence (Holland, Holyoak, Nisbett & Thagard, 1986; Kuhn, 1991; 1993). The specific nature of science from a philosophical perspective has been highly contested in recent years, with cultural relativists refusing to accept science's traditional claims to durable standards of truth, objectivity, and reputable method (Norris, 1997). This has led to one of the arguments against non-traditional forms of writing within science being based on the possible movement away from traditional perspectives of the nature of science (Prain & Hand, 1996). However, one of the components of science literacy is an understanding of the evaluativist view of science that recognizes that multiple interpretations of an experience or data set are likely, but these interpretations must be submitted to public judgment using the available evidence extracted from nature (Hand, Prain, Lawrence & Yore, 1999). Such a position is supported by science reform documents, like Project 2061 (AAAS, 1990; 1993) and the National Science Education Standards (NCR, 1996), where the nature of science is viewed as a speculative, temporary, and rational body of knowledge; this view is a crucial component of science literacy. A synthesis of current science education reforms in English-speaking countries suggested that a scientifically literate person is one who (Hurd, 1998, pp. 413-414):

- Distinguishes experts from the uninformed.
- Distinguishes theory from dogma, and data from myth and folklore.
- Recognizes that almost every fact of one's life has been influenced in one way or another by science/ technology.
- Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
- Senses the ways in which scientific research is done and how the findings are validated.
- Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action.

- Distinguishes science from pseudo-science, such as astrology, quackery, the occult, and superstition.
- Recognizes the cumulative nature of science as an "endless frontier".
- Recognizes scientific researchers as producers of knowledge and citizens as users of science knowledge.
- Recognizes gaps, risks, limits, and probabilities in making decisions involving a knowledge of science or technology.
- Knows how to analyze and process information to generate knowledge that extends beyond facts.
- Recognizes that science concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow.
- Knows that science problems in personal and social contexts may have more than one "right" answer, especially problems that involve ethical, judicial, and political actions.
- Recognizes when a cause and effect relationship cannot be drawn.
- Understands the importance of research for its own sake as a product of a scientist's curiosity.
- Recognizes that our global economy is largely influenced by advancements in science and technology.
- Recognizes when cultural, ethical, and moral issues are involved in resolving science-social problems.
- Recognizes when one does not have enough data to make a rational decision or form a reliable judgment.
- Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion.
- Views science-social and personal-civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences.
- Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow.

- Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social contexts.
- Recognizes the symbiotic relationships between science and technology and between science, technology, and human affairs.
- Recognizes the everyday reality of ways in which science and technology service human adaptive capacities and enrich one's capital.
- Recognizes that science-social problems are generally resolved by collaborative rather than individual action.
- Recognizes that the immediate solution of a science-social problem may create a related problem later.
- Recognizes that short-term and long-term solutions to a problem may not have the same answer.

Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, plausible reasoning (abduction, induction, deduction, and hypothetico-deduction), and skepticism to generate the best temporal explanations possible about the natural world (Johnson-Laird, 1988; McComas, 1998; Yore, 1992). Scientific explanations must be consistent with experimental and observational evidence about nature; and they must make accurate predictions, when appropriate, about the systems studied. Evaluations should be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations about the natural world based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant but they are not science (NRC, 1996).

Writing-to-learn Science

Rowell (1997, p. 46) suggested that learners need to use writing not only as a tool for constructing understanding of science but also as an "enculturation into the community of those practicing science. ... [Writers need to] articulate reasons for supporting claims Ė express doubts, ask questions,

relate alternate views, and point out what is not known". Thompson (1993, p. 108), reporting on a National Academy of Sciences publication about being a scientist, stated that writing in science was critical because of its persuasive power in gaining "communal adherence to truth claims as well as its effect of making scientists thoroughly evaluate their own inductive logic". Thus when writing, scientists need to deal not only with science content but also with the epistemic nature of the knowledge presented (Hofer & Pintrich, 1997).

Writing in university and college science courses designed to promote epistemic insights, thinking, and conceptual understanding requires utilization of science-appropriate genre, like description, instruction, explanation, and argumentation (Martin, 1993; Mullins, 1989). Moore (1993) found college students' science achievement improved if writing was coupled with explicit writing instruction and embedded in actual science courses. Liss and Hanson (1993) found that students who had an internal locus of control appeared to value writing tasks and worked harder than students with an external locus of control. Generally, application of write-to-learn approaches is being more widely used in university and college level science courses than ever before. The University of Hawaii adopted a writing-intensive course requirement for AA, BA, and BS degrees in 1987 (Chinn & Hilgers, 2000). All students must complete five writing-intensive courses in their major area. Writing-intensive courses require that

- writing be used to promote learning.
- student and professor interact during the writing process.
- writing plays a major role in course grades.
- students produce a minimum of 4,000 words or 16 pages of text.
- class enrollment be limited to 20 students.

They found that professors primarily focused writing in demonstrating mastery of content knowledge and discourse practices of the scientific community, and success was greater and more widespread when the professor adopted a collaboration stance rather than an expert critic stance.

Hallowell and Holland (1998, p. 29) stated that "scientific illiteracy among college students is a persistent problem ... yet the need to understand science principles and to be able to make judgments about the value of scientific knowledge and research has never been greater". Science literacy and the related print-based communication requirements need to address the dual goals (writing-to-learn science and technical science writing) of literate adults and literate science professionals. Attempts to address this problem are many; for example, Carle and Krest (1998) described a collaborative effort between a science department and university library to improve the access, collection, and evaluation of science information. This program addressed the "out of context" problem that many university library orientation and writing clinic programs encounter by focusing their efforts on science for science majors and instruction on authentic writing tasks for scientists. They utilized print and electronic science citations and references to track the influence of science discoveries and to locate and evaluate information. Koprowski (1997) and Rice (1998) provided explicit instruction on science writing, exposure to various science writing genre, and actual experience as a peer-reviewer. Koprowski infused writing instruction, writing assignments, and peer-review into science courses. Rice described an advanced stand-alone scientific writing course designed for upper-level science majors in which he served as "guide, coach, cheerleader, critic and occasionally referee" (p. 268). Central to the success of the course were specific instruction and creatively crafted assignments that provided insights into the different genre scientists use to communicate with different audiences: narrative (scientific autobiography), description, explanation, argumentation, and report of original laboratory work (mixed genre). Rice infused explicit instruction on grammar, appropriate voice, word usage and choice, sentence structure, and logical development at opportune times as needs arose. Venable (1998) asked students to re-write chemistry articles from the mass media once they identified incorrect reporting of science concepts. Burke (1995) asked chemistry students to write creative stories about a particular element from the periodic table.

The traditional and non-traditional writing tasks described above enhance student learning because they require students to reflect, consolidate, elaborate, reprocess concepts and ideas central to the topic, hypothesize, interpret, synthesize and persuade, and hence develop higher-order thinking, the

construction of a deeper understanding of science concepts, and greater technical writing proficiencies (Schumacher & Nash, 1991; Sutton, 1992). While these studies have demonstrated potential benefits of writing-to-learn strategies, they have identified additional issues that need to be explored in subsequent research. One issue is the need for more interaction with professional scientists and engineers outside of the academic community in order to better understand the particular writing demands that scientists face in their careers and personal lives (Yore, Hand & Prain, 1999).

Research Design

This study was designed to examine expert scientists' perceptions of good science writing and processes they use when undertaking science writing tasks. The intention of the study was to determine if there are common attributes, values, beliefs, strategies, and criteria that scientists use as they address different writing tasks (function and form) and audiences, which can inform the pedagogical practices of science educators in helping students improve their science writing, science learning, and science understanding. Currently, writing-to-learn science in elementary and secondary schools has little grounding in the writing activities of actual scientists and engineers but rather relies on an array of pedagogical assumptions from other communities. This study assumed that it would be productive to determine if there is common set of purposes, writing types, criteria, and strategies between the scientific and education communities.

The design of the qualitative study consisted of an opened-ended questionnaire followed by an interview. The development of the questionnaire was based on a review of the literature, informal discussions with practicing scientists, and the previous research of the three authors (e.g., Hand, et al., 1999; Holliday, et al., 1994; Prain & Hand, 1996). The 24-item questionnaire was constructed on three major foci. The first focus was to determine the type of writing that scientists engaged in; for example, do they only write for scientific journals read by other scientists or do they write for a broader range of audiences. Questions also focused on the scientists' awareness of their audience and if the target audience had an impact on how they write. The second focus was to explore the criteria that scientists used to judge science writing that they read. Importance was placed on exploring whether scientists used the same

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criteria to judge other scientists' writing and to construct their own writing. The third focus was to explore the strategies used by scientists to complete writing tasks. These questions reflected the processes of writing, like setting purpose, organizing, composing, revising, and editing.

The questionnaire was distributed to scientists who agreed to participate in the study. They were each given two weeks to complete and return the questionnaire. Once the questionnaires were returned, each volunteer was contacted and arrangements were made for interviews to be conducted. The custom-designed interviews ranged in length from 40-50 minutes and focused on asking each scientist to elaborate on their responses on the questionnaire. This enabled the same three foci to be examined in more detail than normally provided in their written responses.

The questionnaires were analyzed independently by the authors based on the three foci. Sharing sessions were conducted by telephone and email to determine common responses, criteria, and assertions in order to produce a list of essential writing characteristics used by expert scientists. The interviews were transcribed by an experienced secretary familiar with qualitative research procedures. The transcriptions were then coded using the assertions produced from the questionnaire responses to seek supportive or non-supportive evidence. Two cases were summarized, reported, and compared to clearly illustrate the diversity in the scientific community sampled.

Results

Seventeen Iowa State University faculty and staff members (3 women, 14 men) responded to the survey. All respondents had an earned Ph.D. in science, applied science or psychology and had a major research responsibility in their university appointment. Nine respondents were professors with greater than ten years of experience, four respondents were professors with less than ten years experience, and three respondents were research fellows or academic professional staff. Each respondent was interviewed after completing the questionnaire. Custom-designed semi-structured interviews were developed for each respondent based upon her/his questionnaire responses. The interviewer attempted to clarify, extend, and elaborate the questionnaire responses and to probe ideas contained in those responses.

A step-wise trend analysis was used to analyze each item on the questionnaire, and the interviews were analyzed to verify trends established from the questionnaire. Responses were grouped by the respondents' experience, pure and applied field of research, and gender as a search for any group trends. Since no category trends were found, the 17 questionnaires were synthesized to reveal any assertions for each area of the questionnaire. Some items were clustered together to form larger, related issues. Once the assertions were established by the researchers, the assertions were discussed and consensus was reached. The consensus assertions from the questionnaire data served as the analysis framework for the interviews. The interview transcripts were color coded to highlight supportive and non-supportive evidence and to elaborate ideas for each assertion. The two cases selected were representative of genders (female, male), disciplines (ecology, physics), and experiences (first-year research associate, 30-year full professor), and were believed to illustrate the range of perceptions, beliefs, and practices.

Assertions

The results from the analyses of the questionnaires and the interviews are reported under the subheading of the three foci for the survey dealing with the type of writing, judgment criteria, and writing strategies. The assertions constructed from these data are expressed in **bold face type,** illustrative quotes from the questionnaires and interviews are expressed in *script type*, while the authors' elaborations are expressed in normal type.

Focus #1: What Types of Writing do Scientists do?

1. What journals or other publications do the respondents write for regularly? **Most respondents wrote for a limited number of journals (3-5 with a range of 2-20) in their specialized research area.** Seven respondents wrote for academic science journals, five respondents wrote for applied science journals, while another five respondents wrote for college science teaching and learning journals. Academic scientists wrote mainly research reports and reviews, while applied scientists wrote to a slightly wider readership; very few respondents wrote for broader audiences and for popular publications like newspapers and magazines.

2. What scientific magazines or journals do you read regularly? **The respondents generally read for professional reasons the same journals they wrote for regularly.** Conservation Voices, National Geographic, Science, Science News, The Science Teacher, Scientific American, and Smithsonian were the only science-related magazines read by a few of the respondents for pleasure. It was somewhat surprising that these experienced scientists had such a limited reading list of journals, but it was not surprising that the majority of their reading was done for professional reasons since keeping current in their specialization is critical to their success as a researcher and their research funding.

3. What types of writing do you do and how frequently do you do them? **Most respondents utilized very few writing types frequently (lecture notes), a limited number of writing types occasionally (journal articles, laboratory notes, field notes), and popular media types infrequently or never (letters-to-the-editor, essays, short articles).** Table 1 summarizes the results reported by 16 respondents (one respondent did not address this item) about the writing types they used and the frequency they used them. Other types of writing and frequency of use mentioned by the respondents were email (discussions with research team members, conversations with friends, tutoring students, etc.), which were used daily; reviews of grant proposals and articles, which were used occasionally; and interpretative summaries of research literature, which were used infrequently. One respondent stated

> [when] *interpreting this information, please keep in mind that in practice one has often several different kinds of writing taking place at the same time. That is to say, it is not at all unusual to be writing different things for different purposes taking place during the same block of time. Often, writing a scientific article for publication will take from several months to over a year. At the same time, one has a number of articles in preparation, each of which is at a different level of completion. I very rarely am able to sit down and write one complete article or one complete item at one sitting.*

Focus #2: What Criteria do Scientists use to Judge Science Writing?

1. When you read what you consider a well-written science article, what are the criteria you use to judge its quality? Are there other reasons to judge an article as poorly written? **The respondents**

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Table 1

Summary of Writing Types and Frequency of Use

Writing Type	1	2	3	4	5
Journal articles (own research or review articles)	6%	31%	31%	19%	13%
Lecture notes (handouts or web)	31%	0%	19%	38%	13%
Grants (peer-reviewed vs. private foundations)	0%	75%	25%	0%	0%
Reports (research summaries, etc.)	13%	50%	38%	0%	0%
Posters	13%	81%	6%	0%	0%
Abstracts	0%	50%	50%	0%	0%
Editorials, letters-to-the-editor of science journal	63%	31%	6%	0%	0%
Seminars/talks	6%	50%	44%	0%	0%
Letters-to-the-editor of newspaper (general interest)	94%	6%	0%	0%	0%
Essays/short articles (science or non-science publication)	56%	38%	6%	0%	0%
Lab notebooks/Field notebooks	25%	19%	31%	19%	6%
Personal use to help understand your research	38%	13%	31%	6%	13%

Note. 1 = Never used; 2 = Infrequently used (a few times each year); 3 = Occasionally (several times per month); 4 = Frequently used (several times per week); 65 = Daily.

judged the quality for science first (accuracy, recent background, originality, creativity, utility, method, data collection, data analyses, results, discussion, etc.) with lesser attention paid to the quality of the written language (concise, focused, minimum jargon, logical flow, correct grammar, limited use of passive voice, visual adjuncts, etc.). Respondents frequently mentioned the clarity and quality of the argument presented in the article. They were concerned that claims were supported by evidence and justified by appropriate theoretical warrants (established, authorized, or canonical science). Two respondents expressed a view of science as a judgment criterion:

I do not get caught up in 'super-reductionistic' approaches, but rather [I] *look at the 'big picture'.*

The author fails to make the case for the conclusions based on the data presented.

Several respondents mentioned that well-written science made effective and appropriate use of visual adjuncts like illustrations, pictures, tables, and graphs. These visual adjuncts were integrated into the printed text with specific connections and descriptions. One respondent believed that well-written science clearly differentiated among observations, measurements, and speculations.

Other respondents mentioned extraneous information, super-specific terminology, opinions not backed up with data, lack of balanced perspectives as science-related features found in poorly written articles. They also said that frequent language and writing errors led them to question the validity of the science and rigor of the inquiry procedures. One respondent suggested that cutting-edge science was always difficult to describe and explain in written English, since there were few connections to established science and the readers' experiences and that frequently new science involved abductions, personal abstractions, and creative inferences.

2. Do you have different standards for what is good science writing in different publications (peer-reviewed science journals, newspapers, popular magazines)? **Most scientists responding believed there were different standards, and they were skeptical of science articles in the popular media.** A minority (four) of the respondents believed that both types of writing should have the same rigor for scientific reasoning but felt that some authors mistakenly equated *science understanding for knowledge of trivia.* Another minority (four) believed popular articles generally contained science errors and were seeking headlines, not understanding. All respondents were uncomfortable with classifying articles in newspapers and popular magazines, such as Time and Newsweek, as scientific. While they indicated that these articles were informative, they were reluctant to place them in the category of science articles. Seven respondents specifically mentioned the audience, the author's responsibility to the audience, and strategies for addressing the non-expert readership (even within the broader science community) as criteria. One respondent equated simplification with ease of understanding, while another equated

simplification to reduced details. Collectively, the respondents mentioned the following ideas for writing to a non-expert audience: relevant applications, cogent flow, clear presentation of the argument, carefully supported conclusions, avoidance of numerical formulas, comprehensive background, broad picture with less detail, and reduced precision. No respondent mentioned the use of linguistic tools like metaphors, analogues, and other conceptual connections to what the readers know (prior knowledge including misconceptions).

Scientists indicated that there was a need for science writing to be easily understood by the reader, and thus this requires that there be clarity in the writing. However, there were two forms of clarity discussed; first was the emphasis on clarity in terms of the science argument. The format of science articles, that of laying *out of the hypothesis, the development of methods, the presentation of results, the interpretation and conclusion,* was seen as being crucial to good writing. However, simply completing the article format was not considered sufficient to ensure good writing. There is a need for the removal of *unsubstantiated statements, conjecture, biases where* [there is] *no closely supported data* and an emphasis [on ensuring] *the conclusions are consistent with the results*. The scientists indicated that they were very skeptical of science papers where the writing was poor and science was portrayed as *black and white*. The second form of clarity involved grammatical clarity. Grammatical clarity was equated with ease of communication, e.g., *science writing is particularly different than any other kind, you are trying to communicate something clearly*. Communication of ideas requires that writers be unambiguous in terms of the language they use and that they focus on *trying to communicate not impress*.

Focus #3: What Writing Strategies do Scientists use in their Science Writing?

1. How do you ensure that the science ideas are accurate? **Most respondents used a combination of procedural guidelines, structured format, external verification, and personal expertise to ensure scientific accuracy of their science writing.** Many respondents relied on colleagues' reactions, peer reviews, and comparisons to the established research literature to ensure that the science reported was accurate and that alternative perspectives and interpretations had been considered. One respondent stated

you might walk down the hall and say gee do you think this is the correct interpretation of this sort of thing.

Apart from the external verification, six respondents indicated they often relied on personal knowledge, analysis of experimental rigor, and valid links among claims, evidence, and theoretical warrants to ensure the accuracy of the science. However, four respondents indicated that simply by adhering to the article format, good grammar, and simple language they were focusing on the accuracy of their work, e.g.,

I try to explain my work with an approach that uses a rationale, objective, methods, results and conclusions or impact format.

Paper has a clearly focused rationale and introduction; hypothesis/objectives are stated up front; methods are clear and complete; results are compartmentalized and related to hypothesis; extraneous speculation kept to a minimum; recapitulate how results adhere to objectives in summary/conclusion section.

One respondent mentioned that in his area of specialization author teams were frequently used:

Almost all of my scientific writing has been with from one to 15 different co-authors, usually with ten or more. The writing is done as a team with usually the one or two individuals who have been responsible for most of the details of the experiments writing the first drafts. Then, the more senior authors join in as the article is fleshed out, rewritten and rewritten a number of times. Major discussions in person, via telephone, e-mail, FAX, etc. take place as the article is developed and finished. It is very difficult to tell in the finished article who has been actually responsible for what.

2. Do you identify who the reader/audience is? **The audience was crucial in determining the style and language used by the scientist.** All the scientists were very aware of the differences required in their writing when dealing with different audiences. They were concerned about presenting quality science in a style, organization, and language level appropriate for the target audience. The use of *technical jargon* was restricted if the audience was outside of their specialization. Different audiences

affect the *language used, sentence structure, terminology and length* of the piece of writing being constructed. Only five respondents addressed an audience outside of the university, whereas, the other scientists focused on different, non-expert audiences, such as undergraduate and graduate students. For example, one respondent described how he matched his writing to the readership:

> *If I am writing for other chemists in my specialty, I can use different words that communicate things. If I'm writing for the Des Moines Register* [a regional newspaper], *I've got a totally different audience and now restrict myself in words .... I may use the technical terms, but then I'll make sure I get in some explanation of the terms.*

Another respondent described how he used an imaginary audience (a former colleague he knew well, his father, a familiar student) and how he wrote for this person using his knowledge about this person's background knowledge, experiences, and critical-response framework. He described a practical example of his strategy for establishing reciprocity of his goals and the reader's needs:

> *Many years ago* [my father] *wanted to know what I do for research. I said I work in the area of electrochemistry. Ah huh was his response. I said that it has to do with the interconversion of the chemical energy and electrical energy. To which he replied ah huh. I said for example, this is the kind of thing that goes on in the battery of your automobile. You can draw electrical power out, but the power originated as a chemical energy. And we recharge it, and that converts back into a chemical energy. Ah ha was his response. Now every time we see each other, he says have you invented any new batteries lately?*

3. Do you have a clear purpose when you begin to write? **The scientists believed that they were writing to inform and persuade.** In particular, the *purpose is to report results of experiments – tell the story to the scientific audience*. Not only was the purpose to share information but also *to influence colleagues*. There was recognition of the need to capture the interest of the audience *and effectively communicate the facts and mechanisms being described*. Importance was placed on providing the information in enough detail for the audience to make informed decisions, e.g.,

> *Sometimes you're writing grants, so you are* [trying to persuade] *people that the work you*

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are [doing] *deserves to be funded. Sometimes, for example, when I write for the meteorology community, they've done a different* [style] *of teaching* [for] *the* [last] *100 years or so, it doesn't change a lot. So we're trying to* [get them to] *think about change, so you need to ... persuasive isn't quite the right word. You need to give them enough information so they assess what they've been doing.*

Several respondents mentioned that the argument presented needed to clearly and logically connect the claims made to the experimental procedures, data, and theoretical background.

4. How do you decide what to write? When does the purpose become clear? **All the scientists had a defined purpose prior to writing but they did not specify that the purpose influenced the structured form of writing.** When deciding what to write, all the scientists responded that they have a clear purpose prior to actually writing. The purpose defines what they write about, e.g., *to publish experimental results or to respond to a call for a grant proposal.* Only one person indicated that the purpose might become clear during the writing process rather than necessarily at the start.

Few respondents recognized that their organization, structure, or form might change for different purposes. Only five respondents specifically mentioned the function-form relationship (genre). They believed that their writing was different if they were writing a report, proposal or abstract, or to inform (explain), persuade (argue), or describe procedures (instruct).

5. Do you have a plan when you write? **Scientists generally used an outline when writing**. Only three respondents said that they did not use some form of outline when they wrote. An outline could be a physical outline that has been written or a mental outline that was used to guide the writing. Six respondents indicated that they have a mental outline prior to writing, which can include *identifying the audience and target journal.* Those who prefer to write an outline tended to shape the outline around the headings for the article. Some respondents used a "reverse engineering" approach to their writing tasks, using purpose and results to work backward to create introduction, background, and methods.

For articles, reports and other formal presentations of ideas, tests and results, the process starts with data interpretation. I usually write my paper around the key tables or

graphs in order to avoid presenting useless information. Results section first, method section [second], *introduction third, discussion/conclusion fourth and abstract/summary last.*

Such a focus on a structured outline was starkly different for the scientists who did not use an outline. These people said that they preferred to just compose rather than go through a more formal outline, e.g.,

I sit at my computer and start composing.

I have a list of ingredients, but I try very hard not to organize it rigidly as an outline.

Formal outlines are terrible impediments to good writing, especially regarding transition ideas and sentences. It is extremely important, however, to have a clear organization for writing in mind.

6. Do you do the library research on the topic before or during the writing? **All the scientists did literature reviews before writing, and many respondents used literature reviews to improve their experimental design.** The writing occurred after the library research for all the scientists; however, four indicated that they continued with literature review during the writing process, e.g., *I do library research at all times before, during and after the actual writing.* Another respondent mentioned the need to do further library research as he encountered holes in his argument and logic. Overall, there was a concern about ensuring that their writing was carefully located within the current literature (intertextuality):

All of a sudden I see a connection that will tie into research that I've read about in the past. I may need to go back and look at it again, research it a little more. It may tie into current research or past research that I've done. Link it to that, but generally it's a process where either I've done the reading, done some writing, done some reading on the writing I'm going to do ... I do some additional reading to support what I'm writing throughout the article.

7. Does what you plan to say ever change during the writing process? **The writing plan changed as a consequence of the interactive, constructive writing process**. Only one person indicated that he rarely changed his plan after he began writing. While the primary focus was on the need to change

grammar, flow and organization of the paper, eleven respondents indicated that they often changed the emphasis of the paper or the interpretation as they wrote, did further library research, and interacted with colleagues, e.g.,

> *Frequently,* [I make] *both working and organization changes,* [but occasionally I make] *new insights.*
>
> *If a new analysis or statistical technique is used, I will sometimes change what I thought I would say. Also, when I look back with greater knowledge, I sometimes wish I had changed even more.*

This emphasis on the recursive, dynamic process of writing and on changing the way in which ideas are expressed was important for clarifying these ideas, e.g.,

> *As I work out an argument I realize a better way to express an idea.*
>
> *I can always improve on my clarity of presentation and will frequently see things could be said in a different way as I write.*

Scientists intuitively believed they improved their understanding as they wrote, but few believed that knowledge building or constructing understanding was the primary purpose of science writing. Most believed knowledge telling was the prime purpose of writing.

8. Do you revise? **All the scientists revised their writing as a component of the writing process**. All the participants indicated that revision was a part of the writing process. Three respondents indicated that they would revise their writing 8-10 times during the process of producing an article. At times they believe they revise *too damn much.* This constant revision appeared to frame the writing process for many of the scientists, e.g.,

> *It may be that I write a paragraph and I'll walk away from it, then come back and think about it. Maybe make some changes to that paragraph, add another couple of paragraphs or a page or something. It will evolve over time.*

However, several respondents cautioned about revising and editing too early in the writing process, without the benefits of the total text and without time for reflection.

9. Do others edit and offer suggestions? **Nearly all scientists used a review procedure to assist their writing, while only four of the scientists used technical editors to assist them.** The procedure for receiving feedback in terms of edit and reviewing varied, depending upon the authorship of the paper. If the article was co-authored, then co-authors were used to assist in the reviewing and editing processes. If the paper was singled authored, then colleagues were used for review purposes. One person indicated that there was a formal review team in his department, which meant he had ready access to a good review service. Two scientists responded that they did not use peer-review before sending an article to a refereed journal; they relied on the peer-review process of the journal. One respondent described the difficulty with using a technical editor, by stating

> *Early in my career, when funding was more plentiful, we did use technical editors, but we found that when we did the articles usually came back much less understandable than they were when they were given to the editors. Unfortunately, the technical editors did not understand the science well enough. Now, the finished products, after the anonymous peer reviews are completed and their suggestions implemented, the manuscripts are sent to the technical editors of the journals who do the last bit of formatting and polishing. Rarely* [do they make] *any changes other than format changes ... at that point.*

10. How do you check your style, grammar, spelling, and punctuation? **Proof reading was the process used to check grammatical issues, but increasingly computer-assisted spell checks and grammar checks are being used.** While proof reading was viewed as the method to monitor style and grammatical issues, computer-based word processing spell checks were predominately used as a means to check spelling. The respondents did not mention any specific software package for identifying technical edits.

Illustrative Cases

Case Study 1. Dr. X is a very experienced physics researcher and administrator with over thirty years teaching at three different universities. Much of his research writing and funding proposals in science is conducted in a large research team with more than ten co-authors. When asked about the main

kinds of science writing undertaken, he answered that he predominantly wrote scientific research articles or lecture notes to explain scientific concepts to students. However, he also commented that the production of this material entailed a range of different kinds of writing including notes to himself and others, outlines, faxes, email exchanges, and much redrafting and editing of others' work. He also commented that he was often working simultaneously on several articles at *a different level of completion*.

His major criteria for defining science writing were that such writing offered *some new and original findings* about science, or was able to convey *understandings about scientific matters*. This writing would place *emphasis on clarity of expression and upon accuracy*. He elaborated these ideas in the following ways:

> *One of the purposes that you write something that is scientific news is so that other people can take your experiment and reproduce it. So that would mean that you are thorough in your explanations. And that of course would be part of the clarity aspect of it, part of the accuracy. We also look for creativity coming out. That would be a little bit different than originality.*

By "originality" he meant the degree of novelty of the research design and findings. However, he was skeptical about popular reporting of science in newspapers and non-science journals. He noted that such writing, while emphasizing *simpler aspects of the topic* could be scientific, provided that accuracy, clarity and originality were evident. Nevertheless, he claimed that most of these attempts contained at least *one major error in the write-up*.

Dr. X incorporated various strategies in his writing of science. He noted that he always has a *clear purpose in mind*, which shapes the planning process, and that he usually started with a *two paragraph* plan before drafting, although this outline was not always written down. However, there was considerable variation in how the writing was produced and the effects of plan and goal changes during the writing process. Team consultations were conducted to clarify overall purpose, wording, structure, and to provide editorial advice on emerging drafts. He noted that the relevant literature was also reviewed before and during the writing process, and that he often acted as an editor for the larger group, adding or

substituting references, clarifying sentences, suggesting paragraph or whole section revisions, because *everything's fair game*.

Case Study 2. Dr. Y is a postdoctoral research associate in applied science with three years teaching experience. The main kinds of science writing she undertakes are journal articles and laboratory and field notes, although she commented that she occasionally writes reports, abstracts, notes for seminars and talks, and also uses writing to clarify her research. Most of this writing is done on her own but reviewed by colleagues. She also claimed to write regularly for a wider general public or a mixed readership of scientists in her specific field as well as general readers.

Her main criteria for effective science writing were stand alone tables and figures *that I can read and understand without going to the text*; clear methods, and well-supported results and discussion that have an obvious statement about what was observed or happened. Stylistically, she looked for *language and style with the correct use of grammar, precise introductions and conclusions, limited use of passive voice, and variety of sentence construction*. She claimed that *passive voice is a problem with a lot of scientific writing*, and *varying the sentence construction makes it more interesting to read*. She considered that different criteria applied for popular reporting of science, because *you didn't need to go into detail about methods or results* for popular journals, but the information and citations needed to be accurate. For her, writing is scientific because it is about the results of a scientific experiment or in the case of writing for lay people, because it is interpreting science.

She used a range of strategies in her science writing. When writing for the general public she simplified the language, making her sentences and length of the article shorter, and generally focused on the needs and background knowledge of readers. She said that a clear sense of purpose guided all her writing. She typically used an outline, either of topics or sentences to guide the writing process: *I would start with an outline with key words, where the introduction is the main point and then I would broaden that so I have complete sentences*. She noted that most ideas occurred at the outline stage, but *once in a while something will pop out from a table or something that I didn't think of writing before, so it gets added even though it wasn't originally intended*. She also edited her work to remove superfluous ideas

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and to refine expression. She noted that most science writing had to conform to the peer-reviewed journal format, but occasionally she had *read a few articles which don't necessarily follow the typical format*, and that *they can be very well written and much more interesting to read from a literary standpoint*.

There are some clear similarities and differences evident in these two cases. Both writers are in strong agreement about the necessary general criteria that define effective science writing. Their focus on accuracy, clarity, and persuasiveness of the particular case is consistent with the responses of the subjects in the study. However, there is a range of ways in which they differ about how writing relates to the research process and the role of popular writing in science dissemination. While Dr. Y clearly acknowledges the value of writing in generating ideas relevant to the research topic, Dr. X views writing mainly as a record of established understandings rather than influencing the process of knowledge building. However, his comments implicitly indicate that group authorship functions to generate as well as record ideas. Both scientists are guided by backward search strategies, such as generating and refining their texts to address a global purpose. Dr. Y also uses forward search strategies to identify new ideas emerging from a analysis of a draft.

Both scientists support the value of popular dissemination of scientific studies. Dr. X is skeptical about the outcomes of this writing, but Dr. Y asserts that this border crossing beyond academic science communities is valuable and necessary. She accepts the idea that science writing can vary legitimately from the refereed journal formats (research report, article review, etc.) emphasized in universities in attempts to interest general readers. While both writers share many views about the essential nature of science writing, these two cases also illustrate the diversity of approaches to science writing across discipline areas, across gender perspectives, across professional experience, and across views of science.

Discussion

The types of science writing, criteria, and strategies described by these 17 scientists were dominated by the academy's priority for publishing research results in refereed, peer-reviewed journals. Science journals tend to be very specialized and put significant restrictions on pages. The well-defined audience and limited space appeared to influence organization, style, and strategies used. Few scientists in

this study wrote for novice audiences, but some wrote for non-expert audiences like scientists from outside their specialty, science graduate students, and general undergraduate students. Above all, the quality of the science reported drove judgments about good science writing; style, language, and grammar were secondary concerns.

Scientists explicitly mentioned informing and persuading the audience as the main purposes of science writing. They appeared to subscribe to a traditional knowledge-telling model of writing but intuitively believed science writing could build knowledge and help construct understanding. Team authorship and attempts to address reviewers' comments appeared to provide opportunities for explicating knowledge transformation, but their interpretation of these experiences did not recognize these knowledge-building efforts. Most respondents described writing as an interactive, recursive, and dynamic process in which the purpose and the target audience (real or imaginary) influenced the writing act. These science writers realized that, as they wrote, they needed to seek external verification (intertextuality) and use internal monitoring (backward search) to ensure clarity of their argument and clarity of their writing. A small minority believed that reliance on the "scientific method" and the traditional research report format resulted in good science, good science writing, and clear, persuasive arguments.

While adopting the three-stage writing process of planning, translating and revising, the respondents did not explicitly mention the metacognitive functions attributed to this process. Nearly all of the respondents planned their writing, and all were very conscious of the language needed to translate their message for a target audience; they were primarily focusing on relaying information to their audience. The revision dimension tended to focus on statements about grammar and trying to make the message as clear as possible. Although they did recognize that they were able, after many drafts, to construct a clearer message, they did not indicate an awareness of the cognitive benefits to themselves of producing this explanation and clearer conceptualization. They appeared to disconnect the verbal interactions about their writing and the embedded ideas as being part of the writing process. Therefore, these scientists did not recognize the full impact of composing on their understanding of the central ideas.

It is hard to believe that team meetings to consider draft reports or to address reviewers' comments about style and content did not focus their discussions and clarify their thinking about their understanding.

Few of these scientists explicitly reported using different forms of writing to address different purposes, with most being reluctant to view non-traditional science writing, such as articles in popular magazines and local newspapers, as being scientific. This academic view of science writing means that they were unaware of the multiple function-form relationships called genre, with only a few respondents implicitly mentioning the explain, instruct, and argue genre when discussing the various writing tasks encountered.

These scientists indicated using an array of writing strategies focused on the research report, but most of their discourse knowledge about how structural relations were signaled in science writing was tactic. They reported drafting and redrafting, peer reactions and comments, and editing as the main strategies. Several respondents mentioned characteristics for good writing but did not explicitly convert these criteria into procedural strategies, i.e., visual adjuncts. Most scientists mentioned audience background as a prime influence on their consideration of reciprocity; but their only strategies for addressing background were terminology, sentence length, and comprehensive introductions. No respondent mentioned strategies for engaging the audience's prior knowledge, like metaphors, analogies, refutation text, etc.

The respondents reflected Galbraith's (1992) concept that experts tend to deal with each dimension of the process separately. Several scientists advised their graduate students to avoid revising until they were provided the benefits of visualizing the total report. Some scientists reported reverse engineering the writing task by utilizing the purpose and the critical data analyses to guide the development of the introduction, background, and methods sections. The operation of author teams illustrated a separation of subtasks and recursive progression of the development.

The skepticism associated with non-traditional science writing reflected the scientists' perception of the nature of science. Unless the article was able to clearly demonstrate an adherence to the "scientific method" and research report format of hypothesis, procedures, evidence, results and discussion, then it

was not considered good science. The popular works of Hawkins and Sagan were not seen as science because they were only describing the authors' personal beliefs. They did not appear to recognize that their own constructed explanations of research results were personal beliefs. It appears as if most of the respondents were traditional realists and ascribed to an absolutist view of science. This perspective would appear to impact on the potential for these scientists to expand the types of writing they used.

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